Reconfigurable Antenna Aperture with Optically Controlled GeTe-Based RF Switches

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Abstract: *We have characterized the ON state DC electrical resistivity and OFF state capacitance of GeTe-Based RF Switches under direct optical laser excitation. Our tightly-coupled dipole array exhibits performance in excess of 4 to 1 bandwidth over wide-scan angle up to 60 degrees with in-band rejection capability using reconfigurable baluns. Integration of optically-controlled GeTe-Based RF switches at the antenna aperture extends reconfiguration flexibility.*

Keywords: Phase change material; GeTe; RF switches; direct optical laser excitation; tightly-coupled dipole array; wide-scan; wideband; reconfigurable balun.

Introduction

Modern military phased array antenna systems for radar and communication applications in a contested environment require being flexible, adaptable and reconfigurable. There is a growing demand for reconfigurable antenna systems with increased mission functionality and decreased developmental timescales at reduced fielded system cost. In addition, there is a strong desire to aggregate both narrow and wideband antennas on platforms to reduce interference, maintenance, and air-worthiness certifications.

Well-known connecting array architectures [1]-[5], including connecting bowtie, tightly-coupled dipole, planar ultra wideband modular antenna, and thumbtack arrays, have been demonstrated to exhibit very wide bandwidth over large scan angle. This design approach departs from these conventional phased array antenna systems by synthesizing reconfigurable baluns and optically-controlled phase change material bridges to form an innovative antenna aperture that allows in-field and on-the-fly adjustments to linearity, bandwidth, polarization , and frequency to fit many mission scenarios and system needs.

Theory of Operation

In the proposed reconfigurable connected array (Fig. 1), switch bridges in the printed radiator surface, implemented using phase change material (PCM), enable individual radiating elements to be interconnected in a wide variety of shapes to control the spatial pattern. The toggling control of the PCM bridges is achieved using a pulsed laser to heat individual GeTe PCM switch elements. The laser energy is delivered via optical fibers. At the array level, multiple PCM switch elements share a common laser source connected to an optical fiber switch. The radiating element is fed by a novel wideband balun capable of providing fine frequency and bandwidth tuning over wide instantaneous bandwidth. The reconfigurable balun is a Marchand type,

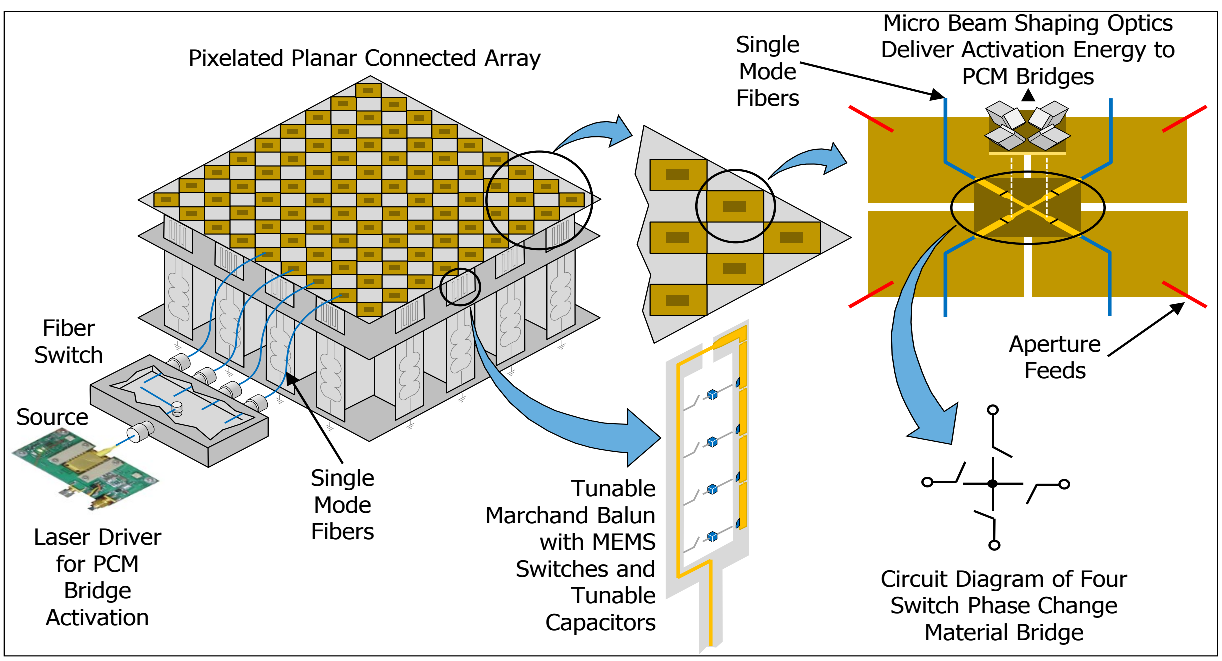

Figure 1. Block diagram of integrated optically-controlled pixelated connected array

which includes the interplay of the open and shorted stubs. Strategic insertion of switches, tunable LC loading, or capacitive loading within the balun structure allow flexibility in reconfiguration of center operating frequency, band selection and band rejection.

Enable Components

Referring to Fig. 1, the integrated reconfigurable aperture includes PCM bridges, reconfigurable balun, and optical control circuit. The following subsections provide details on each component's design and implementation.

PCM Switch: The RF switch material is based on phase change phenomena exhibited by the chalcogenide family of materials. The material development had been previously demonstrated [6]-[8]. The first demonstration of in line phase change RF switch with integrated thin film heater had been reported by El-Hinnawy et al. [9]. In this report, the heat source is generated by a laser pulse. Depending on the magnitude of temperature rise and the cooling rate, crystalline or amorphous phases will be formed. To change states, Fig. 2, a heat pulse with short duration (~100ns) but high amplitude raises the material's temperature above the melting point. As a liquid, the atoms are randomly distributed relative to their neighbors. Rapid quench cooling (~100ns) then freezes these atoms into an amorphous solid, locking in a high electrical resistance state. By contrast, application of a longer pulse width with moderate amplitude raises the material's temperature slightly above the crystallization temperature. If the pulse is of appropriately long duration, the structure experiences atomic bond rearrangement and leads to the low resistance phase. The material offers an off/on ratio of 2×10^7 when comparing the as deposited amorphous state and the crystalline state.

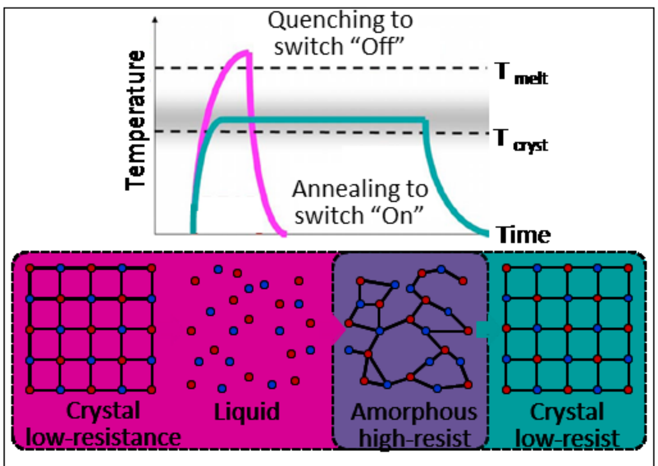

Figure 2. Temperature-dependent PCM State Change

Low On-state resistivity is achievable using PCM bridge geometries with high aspect ratio. Fig. 3 shows the thermal model developed to determine the optimum PCM bridge configuration for a given laser excitation. It is shown that for a 1W laser source pulsed at 100ns, there is sufficient optical energy to heat and melt a 100nm thick GeTe PCM area of approximately 3μm^2.

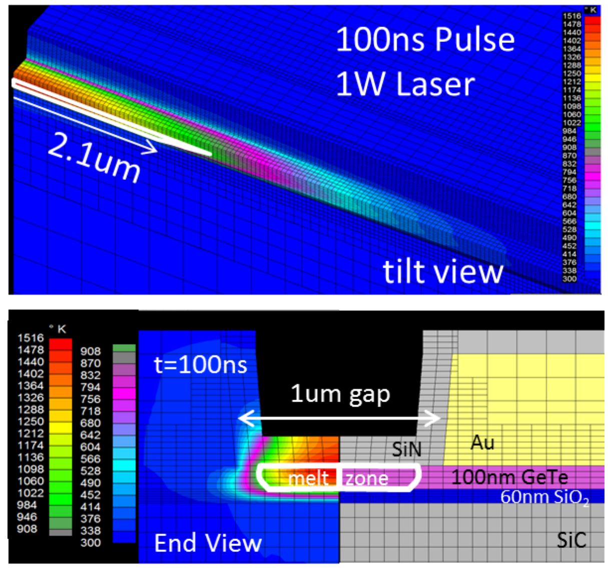

Figure 3. Optimum PCM area under direct laser excitation

The thermal model provides accurate prediction of minimum power to amorphize under laser excitation, as shown in Fig. 4, which tracks well with previously published thin film heater model [9].

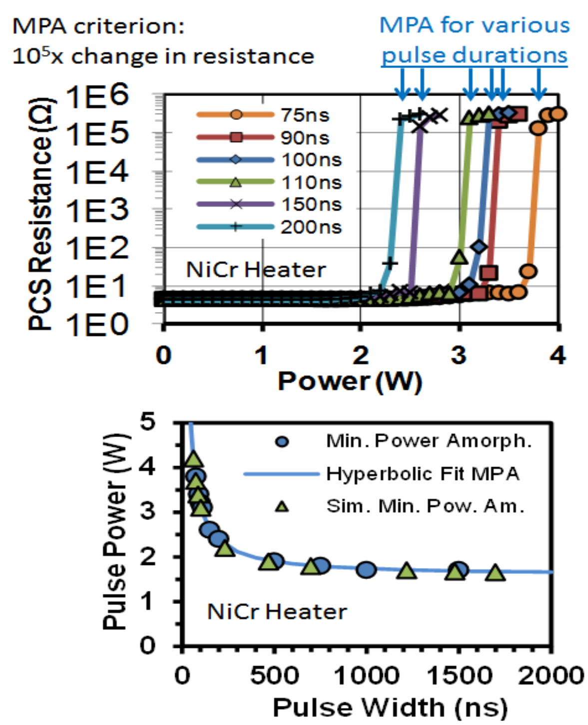

Figure 4. Validation of Melt/Quench Thermal Model

Optical Control: The optical fiber coupled laser light, which will be used to activate PCM switch transition, offers a light weight, scalable, highly localized energy delivery to

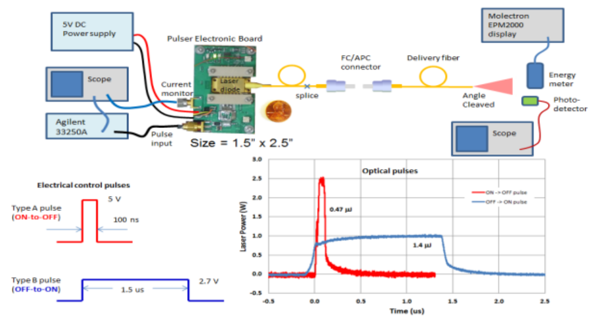

Figure 5. Block diagram of integrated optically-controlled pixelated connected array

each switching element with near zero disturbances to the antenna radiation pattern. Precision power and timing profiles of optical pulses controlled by pulser electronics are shown in Fig. 5. A laser pulse of approximately 2.5W with 100ns pulse width is required to change the GeTe PCM switch from the crystallized state to an amorphous state. Smaller laser power amplitude of approximately 1W with longer pulse duration of 1.5µs is needed for recrystallization. Fig. 6 shows an image of the test setup for direct laser excitation of GeTe PCM switches.

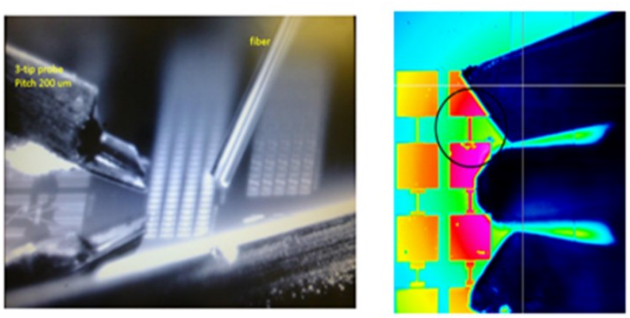

Figure 6. Optical bench test of GeTe PCM switch

The DC resistivity measurement is made using a Keithley Pico-Amp Meter with a 3-tip probe at 200µm pitch, shown on the right hand side of the image. False color image of GeTe PCM bridge 15x5µm (LxW) at the switched sates is shown in Fig. 7. Prior to laser excitation, the PCM bridge is measured at 103Ω (left image). The PCM bridge off state is measured at 4.4 KΩ after laser activation (right image). These values are consistent with electrically activated PCM bridge devices.

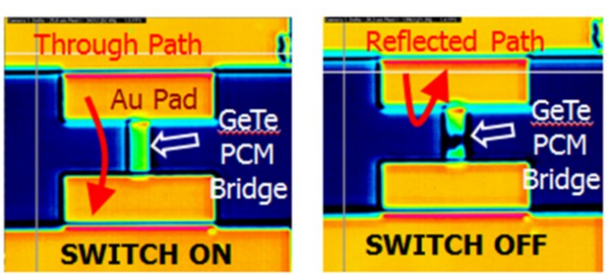

Figure 7. True/False Color Image of PCM at ON & OFF

Repeatable toggling between ON and OFF states using direct laser excitation of a GeTe PCM 2x5µm bridge (LxW) is shown in Fig. 8. Prior to laser excitation, ON resistivity is measured at 23Ω. After laser toggling the PCM to the amorphous state, the OFF resistivity averages at 1.5MΩ.

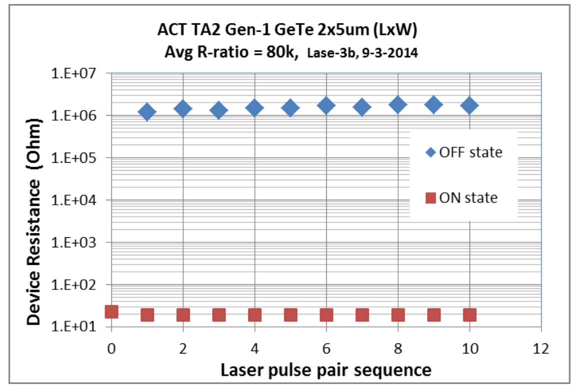

Figure 8. Repeatable Toggle Between ON and OFF

Reconfigurable Balun and Antenna: The wideband, widescan performance of a tightly coupled dipole array (TCDA) with integrated balun has been previously published [2].

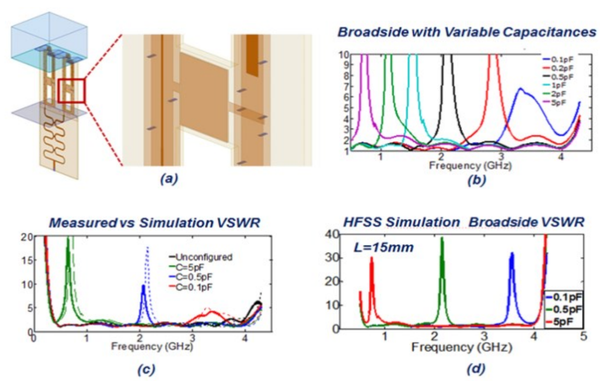

Figure 9. Simulation results of tunable band rejection

A band rejection concept tunable in frequency and bandwidth is introduced in this report. The implementation of variable capacitor values and location of shunt elements allows flexibility in bandwidth and frequency reconfiguration. Four prototype circuits were fabricated including un-configured balun, and integrated capacitance values of 0.1, 0.5 and 5pF, as shown in Fig. 9. The measurement was made with the radiator replaced by a 100Ω chip resistor. It is demonstrated by simulation that at broadside, the dipole input impedance is approximately 100Ω. Full wave simulation models comparing dipole antenna and chip resistor is shown in Fig. 10.

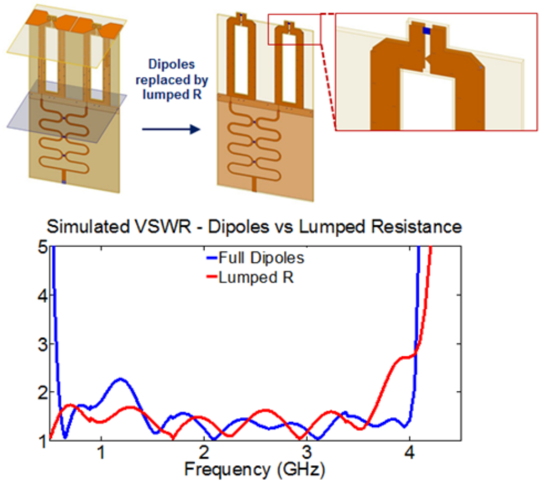

Figure 10. Dipoles vs lumped resistance comparison

Our initial simulation results indicate frequency reconfiguration can be achieved within the operating frequency range of 0.5-4.0 GHz. Bandwidth selection can be dynamically controlled using PCM switches integrated on top of the antenna surface, located in between radiating elements. In normal operating condition, the PCM switches are in the ON state configuration (crystallized state). The radiating elements are connected through PCM bridges, forming a connected dipole array. A non-connected dipole array is created when the PCM bridge is switched to OFF. The performance of a 2Ω ON state and 2KΩ OFF state is shown in Fig. 11. Band rejection at lower frequency region is expected in the OFF state when the radiating elements are changed from connected dipoles to resonant dipoles.

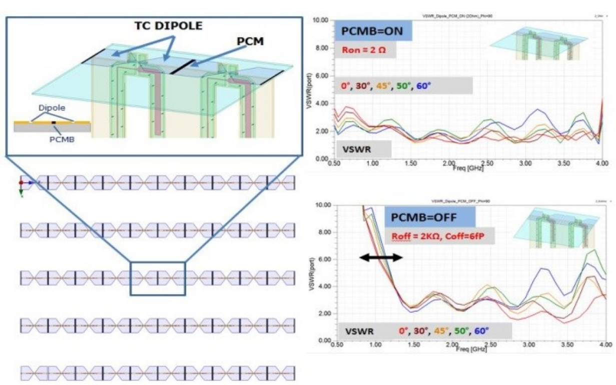

Figure 11. Dipole array in ON and OFF states

Conclusion

Recent developments in fabrication and design of GeTe PCM bridges allow realization of high performance RF switches. Integrated optical excitation of such device and its implementation on radiating surface create a new class of optically-controlled reconfigurable antenna. Future study includes further investigation of real-time reconfiguration for frequency, bandwidth and polarization.

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